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Distribution and Relative Impact of Avian Predators at Aquaculture Facilities in the Northeastern United States

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Abstract.—We conducted on-site interviews at 61 randomly selected aquaculture facilities in the northeastern United States and initially censused fish-eating birds at 58 of those facilities in June 1995 to determine the distribution of avian predation problems. To examine the relative impact of these birds, we continued to study bird populations and the fish consumption rates of these birds at 30 facilities during the summer of 1995 and at 7 facilities during the spring of 1996. Approximately 80% of the fish culturists interviewed perceived bird predation to be a problem at their facility; this view was even more widely held by trout producers. Consistent with these results, 81% of the facilities surveyed during the first phase of study had at least some fish-eating birds present. When asked to list bird predators in order of importance, 76% of 49 managers responding named the great blue heron *Ardea herodias* as the most important predator of concern. Consistent with these findings was the presence of great blue herons at 90% of the 30 facilities repeatedly surveyed during the summer of 1995. Based on damage projections, common grackles *Quiscalus quiscula,* mallards *Anas platyrhynchos,* and great blue herons appeared to be the primary species of concern out of 10 bird species observed. However, mallard problems were relatively isolated, and previous damage estimates reported in the literature for mallards, common grackles, and American crows *Corvus brachyrhynchos* may have been highly inflated. Of the 24 trout-rearing facilities surveyed during the summer of 1995, 21% were estimated to have sustained bird predation losses in excess of US$10,000. Smaller losses, ranging from several hundred to several thousand dollars, were more typical of the remaining trout and warmwater fish facilities.

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Avian predation on fish stocks has long been recognized as an economic concern by aquaculture producers (Cottam and Uhler 1937; Lagler 1939; Pough 1941; Draulins 1988). More recently there has been considerable effort to determine the scope and magnitude of losses caused by avian predators at aquaculture facilities (Parkhurst et al. 1987, 1992; Schramm et al. 1987; Hoy et al. 1989; Parkhurst 1989; Stickley et al. 1992, 1995; Ross 1994; Glahn and Brugger 1995; Pitt and Conover 1996). Attempts to examine the scope of the problem over large geographic areas have relied primarily on questionnaire surveys (Parkhurst et al. 1987; Stickley and Andrews 1989). However, there has been little attempt to verify producer perceptions concerning predation at their facilities.

To estimate the extent of avian predation, most investigators have relied on observational techniques that involve using the following variables: (1) mean bird use of the facility throughout the day, (2) days that birds are present during the year, and (3) mean foraging rates of individual birds. Although there have been few attempts to validate estimates by comparing them to daily food requirements of these predators, Pitt et al. (1998) suggested that simple bioenergetic models can provide a reasonable estimate to the consumption of hatchery fish by birds.

The finfish aquaculture industry in the northeastern United States, centered in Pennsylvania and New York, consists primarily of trout production, but also includes production of warmwater species, such as baitfish, channel catfish *Ictalurus punctatus,* and goldfish *Carassius auratus.* In 1984, a questionnaire survey of producers, primarily in Pennsylvania (Parkhurst et al. 1987), revealed that 63% of producers felt that they had predation problems caused by avian and other predators, but losses specific to birds were not identified. Predation losses were ranked second to cultural losses in affecting production. In contrast, Pennsylvania producers identified predation as their number one constraint on production in 1995 (USDA 1995). In 1985 and 1986, Parkhurst et al. (1992) conducted an observational study and estimated that annual salmonid losses from all avian predators ranged from US$750 to $329,000. Although producers considered great blue herons *Ardea herodias* to be their primary concern, mallards *Anas platyrhynchos* and common grackles *Quiscalus quiscula* were identified as the two most important predators causing losses.

The objective of this study was to determine the distribution and relative impact of fish-eating birds at finfish aquaculture facilities in Pennsylvania, New York, and New Jersey. This included the use of observational techniques to affirm perceptions of producers and simple bioenergetic projections to validate observational techniques.

Methods

Initial surveys of aquaculture facilities were conducted in June 1995 to interview hatchery managers and survey fish-eating bird use at times when birds would most likely be present. From respective state lists of commercial and state aquaculture facilities in Pennsylvania, New York, and New Jersey, we determined the percentage of regional facilities in each state and used this as a basis for sampling facilities proportionally among states. Because of the wide geographic distribution of aquaculture facilities, we used stratified cluster sampling (Mendenhall et al. 1971) to increase efficiency in collecting data. Clusters in each state consisted of groups of contiguous or nearest neighbor counties containing aquaculture facilities. To determine the number of facilities in each county, we conducted brief telephone interviews with facility managers to determine their willingness to participate in the study and to screen out facilities that were housed inside or that otherwise totally excluded birds. Each state was divided into eastern and western strata, with each stratum containing at least two clusters. One cluster was randomly selected from each stratum such that each state had clusters selected from the eastern and western strata. Using this sampling procedure, we surveyed 43 facilities in Pennsylvania and 16 in New York from 15 and 12 counties, respectively. The ratio of trout-rearing facilities to warmwater fish-rearing facilities that we sampled was approximately proportional to their ratio on a statewide basis. Because of the relatively small number of facilities in New Jersey, only one trout facility and one warmwater fish facility were surveyed in that state.

At each of the 61 facilities selected, we questioned the manager about the facility, fish stocks, perception of bird predation problems, and the effectiveness of any control measures. We then conducted fish-eating bird censuses at 58 of these facilities. The first census was conducted during the last hour before dusk; the second during the first hour after dawn of the following day. These times were chosen to coincide with periods when both diurnal and nocturnal predators might be foraging. Only avian predators were considered during these interviews and surveys.

Following the initial survey of facilities in June, we initiated a more intensive investigation of bird populations and their impact on fish stocks in July 1995. A random subsample of 30 facilities from Pennsylvania (22), New York (7) and New Jersey (1) were more intensively surveyed. At these facilities, we censused fish-eating bird populations four times per day during the daylight hours, as well as once or twice at night. Daytime surveys were conducted at 3–5-h intervals between dawn and dusk. Night surveys were conducted 2–3 h after sunset or 2–3 h before sunrise; high-powered spot lights were used to locate and identify birds at night. In Pennsylvania and New Jersey, censuses were conducted twice monthly (five times) from mid-July through the end of September; for logistical reasons, facilities in New York were surveyed monthly (three times). Immediately after each diurnal population census of 10 facilities in Pennsylvania and New Jersey and 7 facilities in New York, we conducted foraging rate observations on focal birds with a spotting scope (15–45× magnification). The criteria for selecting focal birds were as follows: an individual bird of the most numerous species present that was farthest from the observer but still clearly visible. We reasoned that birds furthermost from the observer would be least affected by the observer's presence. Each focal bird was observed continually for up to 30 min or until the bird left the area or no longer could be observed. During these observations, the species, number, size, and condition of fish consumed were recorded, as well as the start and end time of the observation. Sizes of fish were judged by comparing the bill length of the bird to the size of fish in the bill. This was confirmed in some cases by examining size-class of fish in raceway pools where the fish was taken. Each fish captured was categorized as alive or dead as determined by the movement of the fish in the bird's bill.

In 1996, we continued bimonthly population surveys and foraging rate observations at seven facilities in western Pennsylvania from mid-April through the end of June. These facilities were chosen from those previously surveyed during the summer of 1995 because they were representative of the range of avian predator problems previously observed. At five facilities in Pennsylvania and New York known to have great blue heron predation, we conducted diurnal population surveys of fish-eating birds monthly from December 1996 through April 1997 to determine the relative impact of bird predation during the winter. We estimated the fish losses and the economic impact attributable to the three most important avian predators at six facilities in western Pennsylvania using the following two equations. Fish losses: number of fish consumed/year = (mean number of birds seen × hours of bird presence/day) × (days of bird presence/year) × fish consumed/bird-hour. Economic impact: monetary losses = (fish consumed/year) × cost of average fish at size consumed.

We used a moving average of birds seen over time to estimate the mean number of birds seen and used the average number of daylight hours to determine the hours per day that birds were present. The days used per year were estimated based on the first day the predator was observed to consume fish in the spring of 1996 to the last day it was observed to consume fish in the fall of 1995 because winter predation problems appeared infrequent or minor. We used species-specific foraging rate data pooled from all locations and times of day studied to determine the overall average number of fish consumed per bird-hour at facilities. Costs were averaged between facilities based on average species-specific size-class of fish consumed.

Results

Facility Manager Survey

Of the 61 facilities surveyed, 48 (79%) were privately owned, 9 (15%) were state hatcheries, and 4 (6%) were cooperative nurseries administered by the Pennsylvania Fish and Boat Commission. The facilities sampled reflected the diversity of the northeast aquaculture industry; 43 (70%) were primarily trout-rearing facilities, and 18 (30%) cultured various types of warmwater fish, primarily channel catfish and minnows. Of the trout-rearing facilities, 11 (26%) also raised other species of fish. To produce this variety of fish, 42 (69%) of the facilities used raceways primarily for trout production, but 54 (88%) used earthen ponds either alone or in conjunction with raceways to produce both trout and warmwater species. Water area of these facilities varied from 0.03 to 23 ha. Large water areas (>2 ha) were associated with the culture of warmwater fishes in a number of small ponds ranging from 0.04 to 4 ha in size. Trout production was typically in earthen or concrete raceways ranging from 0.03 to almost 2 ha. However, 83.3% of the trout-rearing facilities also used earthen ponds to culture fish. The total water acreage of these ponds ranged from 0.02 to 3.6 ha. They were sometimes used as pay-to-fish lakes. All facilities reported having a range of size-classes, and 46 (75%) held fish year-round in outside rearing structures.

Eighty percent of the 61 facility managers considered bird predation to have been a problem at their facility within the past year. However, we detected a difference (Fisher's exact test, $P = 0.007$) in the perception of managers primarily producing trout compared with those producing warmwater fish. Ninety-two percent of the trout producers considered bird predation to be a problem, but only 61% of the warmwater fish producers believed this to be true. Most managers (72%, $N = 33$) considered bird predation to be seasonal, occurring primarily from summer through fall. The remainder, primarily trout producers, considered bird predation to be a year-round problem. Annual losses of fish larger than fry from all causes were reported by 42 managers. Losses ranged from 1% to 50%, and averaged 16.7%. Managers attributed more than half (55%) of these losses to bird predation. About half (49%, $N = 30$) of the managers responding viewed predation problems to be increasing in recent years. Twenty percent thought the problem was decreasing, while the remainder considered it to be staying about the same. When asked to list bird predators in order of importance, 78% of 49 managers named the great blue heron as the most important predator out of several species usually named. Of the remaining species, only the mallard, common grackle and belted kingfisher *Ceryle alcyon* were named as

TABLE 1.—Frequency of primary bird predator species ranked in order of importance (1 = most important and 6 = least important) by 41 randomly selected finfish aquaculture managers in Pennsylvania, New York, and New Jersey in 1995.

Species	Importance ranking 1	2	3	4	5	6
Great blue heron	38	6	3	0	0	0
Black-crowned night heron *Nycticorax nycticorax*	0	4	0	2	1	0
Common grackle	3	10	7	2	0	0
Belted kingfisher	5	17	7	3	1	0
Green-backed heron *Butorides striatus*	1	8	9	1	0	1
Great egret *Casmerodius albus*	0	1	0	2	0	0
Osprey *Pandion haliaetus*	0	3	2	4	6	1
Little blue heron *Egretta caerulea*	0	0	0	0	1	0
Red-tailed hawk *Buteo jamaicensis*	0	0	0	1	0	0
Great horned owl *Bubo virginianus*	1	2	1	2	2	0
Gulls	0	0	1	1	0	0
Mallard	3	0	1	3	0	0
American crow *Corvus brachyrhynchos*	0	0	0	0	1	0
Diving ducks	0	0	0	1	0	0
Double-crested cormorant *Phalacrocorax auritus*	0	0	1	0	0	0

the number one predator more than once (Table 1). In addition to these, managers considered 11 other bird species to be important bird predators.

Facility managers reported having taken a number of measures to deter fish-eating birds, but had variable opinions about the effectiveness of each (Table 2). Netting and similar exclusion devices were most often rated as completely effective, and almost half (46%) of the 61 managers surveyed had installed netting or similar exclusion systems over part of the facility. Of the 28 systems examined, 71% were temporary netting or wire covers over individual or groups of raceways. These covers were usually removed during the winter. The largest expense reported for deterring birds was $42,040 for construction of a chain link fence and overhead wire system to exclude birds from a 0.63 ha rearing area at one of the largest private trout-rearing facilities in Pennsylvania. Most (76%) of 59 managers reported expenditures of $500 or less annually to deter birds.

Fish-Eating Bird Censuses (Phase 1)

Consistent with interview results, 81% of 58 facilities surveyed for birds had at least some fish-eating birds present. However, there was no association (Fisher's exact test, $P = 0.381$) with birds being observed and managers reporting a bird prob-

TABLE 2.—Number of aquaculture facility managers in Pennsylvania, New York, and New Jersey reporting use and effectiveness of bird predation control techniques in 1995.

Technique	Facility type: State	Commercial	Effectiveness rating[a] 1	2	3	4
Exclusion						
Enclosure		5	5	0	0	0
Framed netting or chicken wire		4	3	1	0	0
Unframed netting	8	16	14	8	1	1
Nylon-wire grids	1	6	3	2	1	1
Fencing		5	0	1	0	4
Screens or covers	2	2	1	3	0	0
Frightening devices						
Exploders		3	0	0	1	2
Shellcrackers	1	4	0	0	2	3
Other auditory		1	0	0	1	0
Scarecrows		5	1	0	2	2
Other visual		5	1	0	0	4
Harassment patrols						
Human	1	13	1	5	6	2
Dog	0	6	1	2	3	0
Geese or swans		2	1	1	0	0
Other						
Shooting	1	4	2	1	1	1
None	1	15	NA	NA	NA	NA

[a] Ratings of effectiveness: 1 = completely effective; 2 = moderately effective; 3 = slightly effective; 4 = ineffective; NA = not applicable.

TABLE 3.—The frequency of occurrence, mean numbers, and mean densities of presumed bird predators censused in the morning and the evening at 58 randomly selected finfish aquaculture facilities in Pennsylvania, New York, and New Jersey during June 1995.

Species	Observed frequency, number (%)	Number of individuals, mean (range)	Density (birds/ha), mean (SE)
Great blue heron	21 (36)	4.62 (1–38)	7.95 (1.90)
Belted kingfisher	23 (40)	1.78 (1–6)	7.13 (1.42)
Mallard	17 (29)	11.71 (1–37)	21.40 (3.36)
American crow	14 (24)	3.00 (1–8)	4.58 (1.00)
Common grackle	26 (45)	13.85 (1–90)	13.61 (2.60)
Green-backed heron	11 (19)	2.45 (1–9)	3.72 (0.72)
Black-crowned night heron	2 (3)	4.50 (1–8)	5.81 (1.87)
Domestic duck	1 (2)	5.00 (5–5)	6.98 (0.00)
Great horned owl	1 (2)	1.00 (1–1)	1.78 (0.00)
Little blue heron	1 (2)	2.00 (2–2)	0.40 (0.00)
American bittern *Botaurus lentiginosus*	1 (2)	1.00 (1–1)	0.32 (0.00)

lem. Birds were observed at a number of warmwater fish production areas but no problem had been perceived. Also consistent with interview results were the predator species observed at these facilities (Table 3). With few exceptions, these were the same species reported by managers to be significant predators at their facilities. Forty-one percent of the facilities censused had no more than one individual of any one species present simultaneously. The largest numbers observed at any one time were 90 common grackles, 38 great blue herons, and 37 mallards. The most commonly observed species was the common grackle, followed by the belted kingfisher and the great blue heron (Table 3). Mallards occurred at the highest average densities, and were the fourth most commonly observed species.

Fish-Eating Bird Censuses (Phase 2)

Repeated bird censuses at a subsample of 30 facilities during the summer and fall of 1995 suggested that avian predators may be more widespread than preliminary surveys had suggested. At least one species of fish-eating bird was observed at 97% of the 30 facilities. Great blue herons were observed, primarily during the daylight hours, at 90% of the surveyed facilities (Table 4), although they had been observed at only 30% of these same facilities during preliminary surveys. Other species occurring at more than half of the facilities included the belted kingfisher, the mallard, and the American crow. Where observed, most species occurred in low numbers, averaging less than three individuals. The exceptions to this were the mallard, the common grackle, and the great blue heron.

Because common grackles foraged at facilities from the beginning of April to the end of June, we estimated that grackle predation occurred during 106 d per year. Great blue herons, green-backed herons, and mallards were first seen in mid-April and were seen during the last observation at the

TABLE 4.—The frequency of occurrence at facilities and where observed, mean numbers, and mean densities of presumed bird predators censused at systematic intervals throughout the day. Bird species were censused bimonthly (five times) in Pennsylvania and New Jersey or monthly (three times) in New York at 23 and 7 randomly selected finfish aquaculture facilities, respectively, from July 1995 through September 1995.

Species	Observed frequency, number (%)	Number of individuals, mean (SE)	Density (birds/ha), mean (SE)
Great blue heron	27 (90)	4.37 (0.83)	9.77 (2.92)
Belted kingfisher	22 (73)	1.57 (0.09)	6.63 (0.94)
Mallard	18 (60)	18.75 (2.40)	26.57 (3.62)
American crow	17 (57)	2.53 (0.21)	6.98 (1.68)
Common grackle	13 (43)	16.34 (3.48)	16.74 (2.87)
Green-backed heron	11 (36)	1.40 (0.16)	2.69 (1.61)
Osprey	8 (27)	1.12 (0.07)	3.28 (0.60)
Great egret	3 (10)	1.83 (0.65)	4.95 (3.74)
Black-crowned night heron	3 (10)	3.35 (0.57)	4.40 (0.75)
Great horned owl	4 (13)	1.00 (0.00)	1.494 (0.44)

TABLE 5.—Rates of trout consumption, lengths of trout consumed, and value of fish consumed by seven avian fish predators observed at aquaculture facilities in the northeastern United States in 1995–1996.

Species	N	Hours observed	Live trout consumed	Live trout consumed/h	Prey length (cm)		Costs per fish consumed (US$)[a]	
					Mean	Range	Mean	Range
Great blue heron	103	62.8	142	2.2	22.3	7.6–35.6	1.47	1.10–1.70
Mallard	164	49.6	205	4.1	10.0	3.8–15.2	0.42	0.37–0.46
Common grackle	148	60.0	150	2.6	7.2	2.5–11.4	0.35	0.24–0.40
Belted kingfisher	11	6.6	11	1.7	7.8	5.1–10.2	0.36	0.24–0.40
Green-backed heron	27	8.0	27	3.1	10.2	3.8–16.5	0.42	0.34–0.46
Osprey	19	8.95	19	2.1	30.9	20.3–61.0	2.55	1.91–3.10
Great egret	6	3.31	8	2.4	14.3	11.4–21.6	0.70	0.50–0.85

[a] Costs per fish were based on the size of fish consumed and the mean commercial value of that size-class from five producer price lists.

end of September 1995; thus, predation was estimated to occur for 168 d. Great blue herons were present at some trout-rearing facilities during the winter, but only intermittently and only one or two individuals. However, at one trout facility 20 great blue herons were observed during the census in January 1997. The only other year-round species observed were one or two belted kingfishers. Most other species were observed too infrequently to discern a pattern of facility use. Ospreys were seen only during presumed migratory periods in April, August, and September.

Foraging Rate Observations

Most foraging rate observations were made on the three primary predators, but observations included four other species (Table 5). Almost all foraging rate observations were obtained at trout-rearing facilities, and all fish consumed were trout. The size of trout eaten varied with the size of the predator. Common grackles ate the smallest trout and ospreys the largest (Table 5). With the exception of the American crow, foraging rates of all bird species ranged from approximately two to four live trout per hour observed (Table 5). During 4.68 h of observations, crows were observed to consume only one dead trout. Common grackles were the only species to eat large numbers of dead fish, and 26% of the fish they ate were already dead. Mallards and great blue herons also consumed dead fish, but dead prey constituted of only 9% and 4% of the total intake, respectively.

Some species were observed to eat trout at some locations but not at others. Mallards were widely distributed (Table 4), but were seen eating trout only at three hatcheries in Pennsylvania, while at other facilities they appeared to feed only on waste feed in settlement ponds or natural vegetation. Mallards and common grackles were observed at a number of warmwater pond-culture facilities, but we have no evidence that they ate fish in these situations.

Estimates of Fish Losses

Among selected facilities, estimated trout losses from great blue herons ranged from 287 fish/year to 19,581 fish/year, with an annual dollar loss ranging from $422 to $28,784/year (Table 6). The largest loss was associated with an hourly mean of approximately four birds seen throughout the day. This number of observed great blue herons occurred at only 2 of the 30 facilities observed. Losses of $442 to $1,240/year were associated with an hourly mean of 0.05–0.17 great blue herons, or one or two birds observed in the morning or evening. This was typical of great blue herons seen at the remaining 25 facilities during the summer of 1995. At warmwater aquaculture facilities, we have fewer data to assess losses. However, as at smaller trout-rearing facilities, only one or two

TABLE 6.—Observational estimates of bird use, fish losses, and economic impact from great blue herons at four trout-rearing facilities in Pennsylvania during July–September 1995 and April–June 1996.

Facility	Mean number of birds seen	Mean hours per day	Days per year present	Total bird-hours present	Fish consumed per hour	Total fish consumed	Cost per fish (US$)	Total loss (US$)
Reynoldsdale	3.867	13.6	168	8,900	2.2	19,581	1.47	28,784
Bellefonte	0.168	13.6	168	384	2.2	844	1.47	1,240
Elk Creek	0.072	13.6	168	166	2.2	364	1.47	535
Benner Spring	0.057	13.6	168	130	2.2	287	1.47	422

TABLE 7.—Observational estimates of bird use, fish losses, and economic impact from mallards at three trout-rearing facilities in Pennsylvania during July–September 1995 and April–June 1996; 15 other facilities with mallards had no observed predation.

Facility	Mean number of birds seen	Mean hours per day	Days per year present	Total bird-hours present	Fish consumed per hour	Total fish consumed	Cost per fish (US$)	Total loss (US$)
Bellefonte	13.73	13.6	168	31,372	4.13	129,567	0.42	54,936
Pleasant Gap	2.99	13.6	168	6,843	4.13	28,262	0.42	11,983
Benner Spring	1.40	13.6	168	3,199	4.13	13,210	0.42	5,601

great blue herons were observed during the morning and evening at warmwater facilities.

Estimated losses from mallards were calculated at the only three facilities where these birds were seen eating fish (Table 7). No predation by mallards was observed at 15 other facilities. Estimated trout losses from mallards ranged from 13,210 fish to 129,567 fish valued at between $5,601 and $54,936 (Table 7). These losses were associated with an hourly mean of 1.4–13.73 mallards seen throughout the day.

Estimated losses from common grackles were calculated at five selected facilities surveyed during the spring and early summer of 1996, where significant grackle problems were known to occur. Estimated trout losses from common grackles ranged from 5,862 fish to 66,914 fish valued from $2,047 to $23,286 (Table 8). These losses were associated with an hourly mean of 1.54–17.52 common grackles seen throughout the day.

We have less data to estimate losses from other avian predators. However, assuming average bird populations throughout the expected damage period, maximum losses from other avian predators would not exceed $4,000/year at each of the 30 facilities repeatedly surveyed.

Discussion

Bird predation is a widespread problem caused by a number of bird species at finfish aquaculture facilities in the northeastern United States, and producer perception about the scope and nature of the problem appeared accurate. The same species were implicated as fish predators at 10 Pennsylvania trout hatcheries in 1986 by Parkhurst et al. (1992), but based on our observations, the impact of American crows may be negligible. Although Parkhurst (1989) reported that crows ate live trout, he did suggest that his estimate of damage was overstated because of the dead and dying fish that these birds seemed to consume. Consistent with our findings, producers did not consider crows a threat to fish production.

Common grackles, mallards, and great blue herons appeared to be the primary predators with the largest impact on the northeastern U.S. aquaculture industry. Our estimates of days of predation and size-classes of trout consumed by these predators were consistent with findings of Parkhurst et al. (1992). However, our estimates of loss may not be directly comparable with theirs because they used only site-specific data to calculate losses; we calculated mean species-specific foraging rates from a larger sample of observations between sites and factored this with average site-specific daily predator use and the estimated maximum number of days of bird predation. We reasoned that predator use was site specific, but that actual species-specific foraging rates were less site specific and best determined from larger sample sizes. Although our projections may be somewhat less site specific, they provide the potential expected loss at each site from these predators. However, losses from great blue herons may be larger because our estimates do not include possible predation during the winter months.

TABLE 8.—Observational estimates of bird use, fish losses, and economic impact from common grackles at five trout-rearing facilities in Pennsylvania during April–June 1996.

Facility	Mean number of birds seen	Mean hours per day	Days per year present	Total bird-hours present	Fish consumed per hour	Total fish consumed	Cost per fish (US$)	Total loss (US$)
Cedar Springs	17.520	13.7	106	25,442	2.63	66,914	0.35	23,286
Reynoldsdale	11.735	13.7	106	17,042	2.63	44,818	0.35	15,597
Pleasant Gap	5.04	13.7	106	7,319	2.63	19,248	0.35	6,699
Bellefonte	4.63	13.7	106	6,724	2.63	15,464	0.35	5,382
Benner Spring	1.547	13.7	106	2,236	2.63	5,862	0.35	2,047

As correctly identified by hatchery managers, the great blue heron appeared to be the most widely occurring problem species. Together with mallards and common grackles, great blue herons inflict some of the most serious losses to trout facilities. Based on loss estimates elsewhere (Hoy et al. 1989; Stickley et al. 1995), great blue herons may be of equal concern to warmwater fish producers in the region. Our range of trout losses for great blue herons is consistent with estimates at trout hatcheries in the western United States (Pitt and Conover 1996). Parkhurst et al. (1992) reported somewhat lower losses from great blue herons and ranked their importance fourth after the mallard, the common grackle, and the American crow. In part, our higher loss estimates may be the result of greater great blue heron numbers. Peak numbers of great blue herons had more than doubled at three facilities that had been surveyed 10 years ago. The value of larger fish has also doubled over the past 10 years. Considering that a free-ranging great blue heron is estimated to consume approximately 300 g of trout per day (Schramm et al. 1987; Bennett 1993) or approximately three 22-cm trout, a great blue heron foraging exclusively at one facility could consume approximately 500 trout during a typical 168-d predation season. This loss is consistent with the range we calculated for three facilities used intermittently by one or two great blue herons.

Parkhurst (1989) reported a loss of 386,648 trout to mallards, but our estimate at the same facility was only one-third of this number. Mallard numbers were actually higher during our surveys. We observed up to 120 mallards at Bellefonte Fish Culture Station, while Parkhurst (1989) reported a maximum number of 44. To inflict losses approaching those estimated by Parkhurst (1989), each of the 120 mallards would have to eat more than its entire daily dietary need of 115 g/d (Sugden 1979) for the entire 168-d period. In fact, mallard numbers were on average less than half of the maximum, and mallards met part of their dietary needs by feeding on fish ration.

The common grackle was also a widespread problem species that caused substantial losses at trout-rearing facilities, but previous loss estimates may also have been greatly inflated. For example, at the Cedar Spring Hatchery, Parkhurst (1989) estimated that common grackles at raceways (averaging approximately five birds throughout the day) removed 343,444 trout during 102 d of foraging. In contrast, our estimates, based on similar bird numbers, were only 66,914 trout during a 106-d period. To explain these large losses due to common grackles, Parkhurst (1989) estimated that 30 nesting pairs and nestlings in the area were existing on a diet exclusively of live fish and consuming approximately 78% of their body weight per day. A more reasonable estimate of food intake for the common grackle would be 15% of body weight (White et al. 1985), and food intake for juveniles would not exceed those of the adults (Kendeigh et al. 1977). Assuming the same number of breeding pairs foraging here in 1996 (the maximum number seen at any one time was 75 individuals) and that each adult common grackle consumed 15% of its average body weight (115 g) or 17.25 g of fish per day, 60 adults would consume 18,285 g of fish during 106 d. If we also assume that 120 juveniles would have the same food demand over the entire 106-d period, this would result in an additional 219,420 g of fish consumed. Based on these estimates and the weight of a 7-cm trout at 4.1 g, the entire colony would consume 237,705 g of fish or 57,625 trout. Although more individuals might be involved in grackle predation situations, the fact that 26% of the fish eaten may be dead and the likelihood that their entire diet is not fish makes our projections more reasonable.

The black-crowned night heron is probably causing significant losses in more isolated situations, but our sampling procedures precluded detecting losses caused by this species. Large losses have been reported for this species at trout hatcheries in the western United States (Pitt and Conover 1996), and Hubley (1992) reported heavy losses at a large state-owned facility in Pennsylvania.

Although belted kingfishers, green-backed herons, great egrets, and ospreys prey on trout, only mallards, common grackles and great blue herons were involved in losses estimated to exceed \$10,000. Of the 30 facilities repeatedly surveyed during the summer and fall of 1995, 5 (21%) of the 24 trout-rearing facilities surveyed appeared to be experiencing losses of this magnitude. These losses occurred at almost half of the 11 larger state and commercial trout-rearing facilities surveyed from predation caused by great blue herons, mallards, and common grackles. Smaller losses, ranging from several hundred to several thousand dollars, were estimated for the remaining 19 trout-rearing facilities. With one exception, these losses occurred from great blue herons alone or in combination with other species. The exception to this was one facility where the only predator appeared to be the belted kingfisher. Like predation losses, most expenditures reported for deterring birds were relatively small. Although netting and other exclusion systems are widely used and in many cases are highly effective, their cost may be prohibitive in other situations. Thus, an accurate means of assessing losses is needed to justify such investments.

Although observational techniques may be a viable means of estimating predation losses, they may lack precision in some situations. While the consumption of fish in the process of dying from other causes may inflate these estimates, observational techniques do not incorporate losses caused by predators injuring but not eating fish. Additional studies, using other methods, are needed to directly measure actual fish production losses due to bird predation.

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